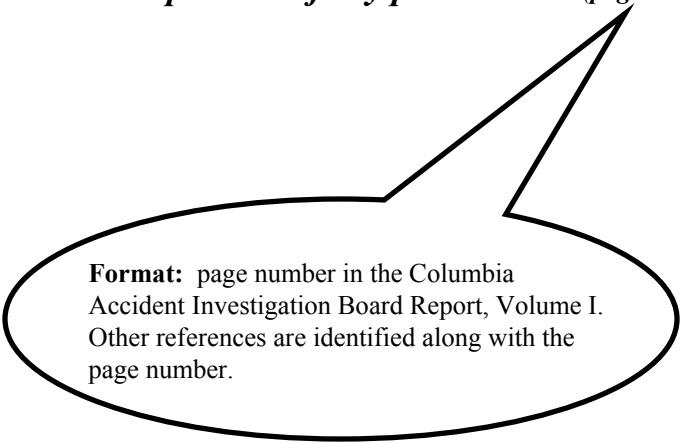


# The NASA Columbia Investigation Report

## And EM

*“Organizational culture defines the assumptions that employees make as they carry out their work; it defines “the way we do things here.” It is a powerful force that persists through reorganizations and the departure of key personnel.” (page 101)*

*Columbia Accident Investigation Board Report  
Volume I, August 2003*



**Format:** page number in the Columbia Accident Investigation Board Report, Volume I. Other references are identified along with the page number.

Presented by: Joe Nolter  
DOE Facility Representatives Workshop  
May 19, 2004  
(202-586-5065)

## Noteworthy Columbia Investigation Board Observations:

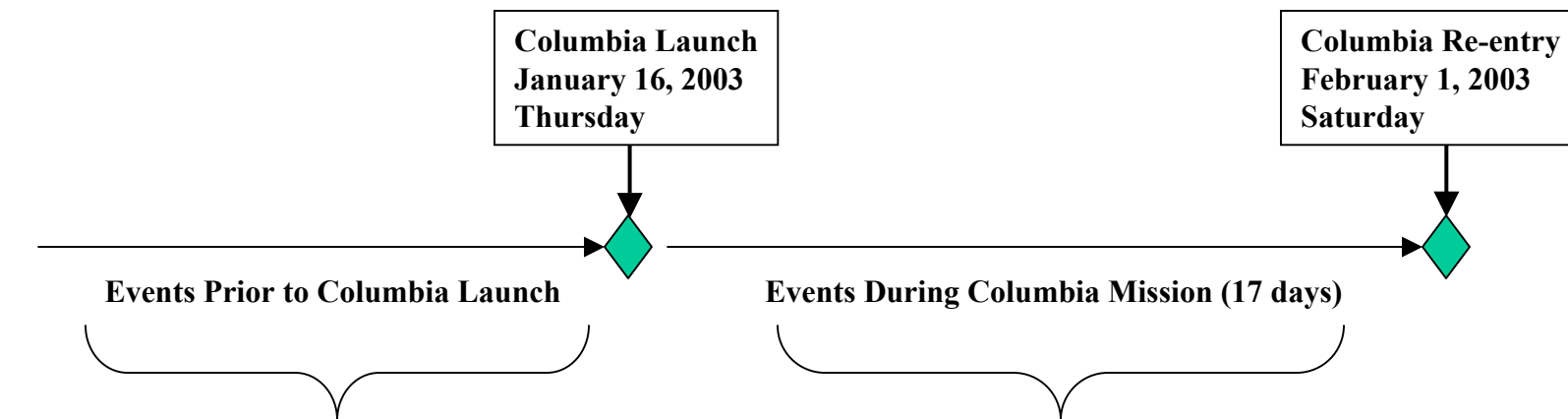
“The Board recognized early that the accident was probably not an anomalous, random event, but rather likely rooted to some degree in NASA’s history..... Accordingly, **the Board broadened its mandate at the outset** to include an investigation of a wide range of historical and organizational issues.....” ( page 9)

“... **management practices** overseeing the space shuttle program were as much a cause of the accident as the foam that struck the left wing.” (page 11)

“Both Columbia and Challenger were lost because of the **failure of NASA’s organizational system.**” (page 195)

# Timeline of NASA's Major Managerial Changes, Events and Decisions

This briefing focuses on the following specific elements and “drills down” into the NASA management system.



## Management System Elements: Part I

1. Funding History
2. Mandate for change
3. Contracting Strategies
4. “Faster, Better, Cheaper” Initiative
5. NASA’s Shuttle Performance Metrics as of January 16, 2003

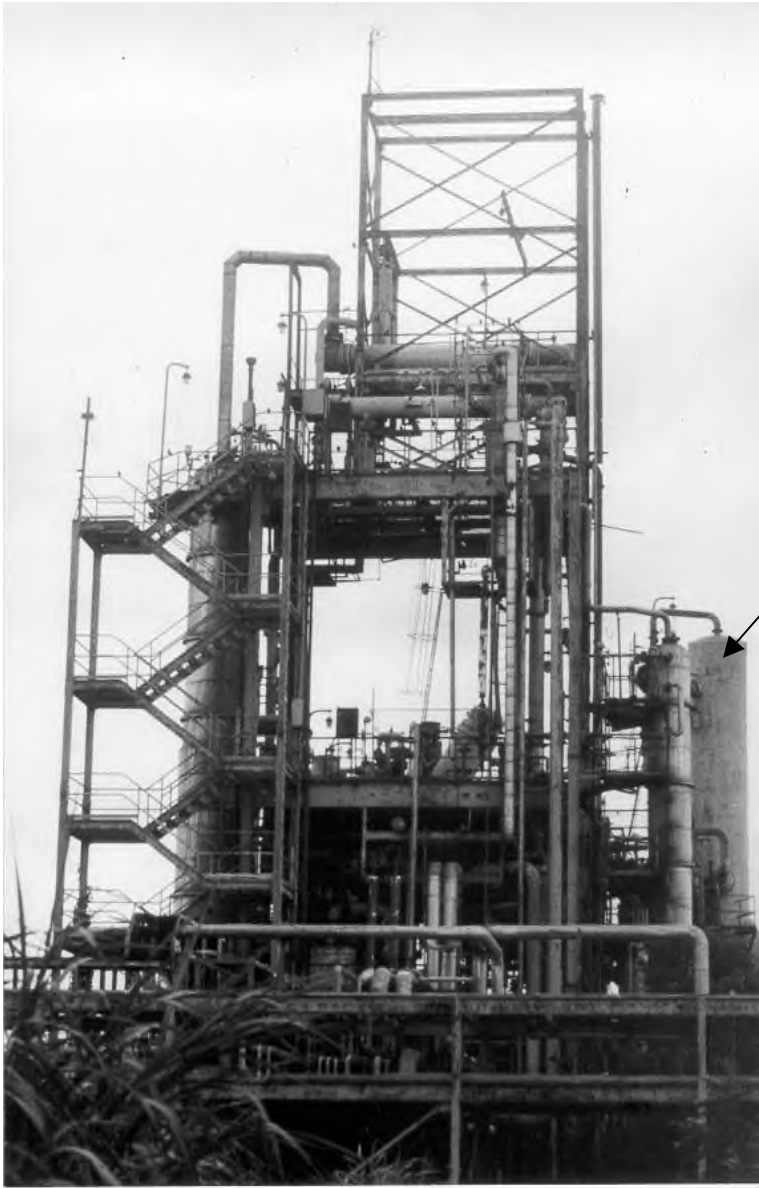
## Management System Elements: Part 2

6. Safety Culture – Management’s Role
7. Technical Lessons Learned
8. Oversight of Contractors
9. Deviation from Requirements
10. Engineering by Viewgraphs

## Situation #1: Worker conducting tool grinding / sharpening operation



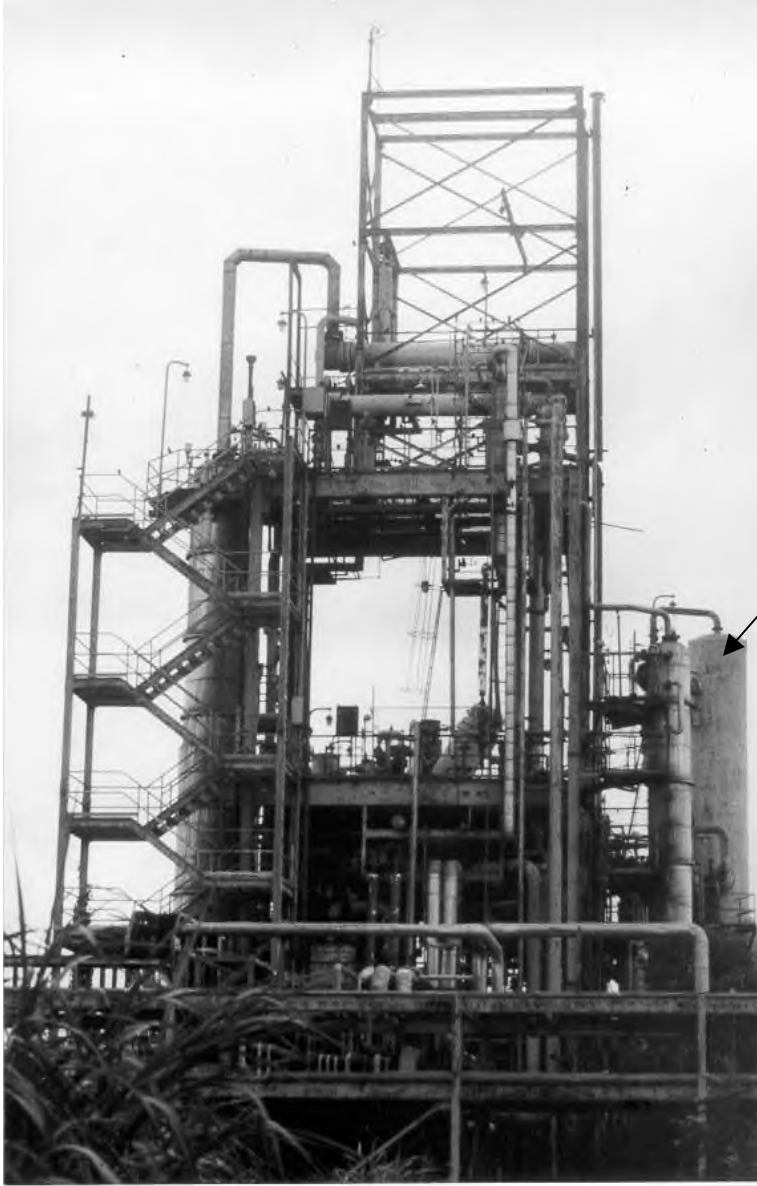
## Situation #2: Chemical Storage at Pesticide / Herbicide Manufacturing Plant



**Tank Contents:** Methyl Isocyanate

## **Situation #2: Bhopal Pesticide & Herbicide Chemical Plant**

**(Union Carbide India Limited)**



**Tank Contents:** Methyl Isocyanate  
**Amount:** 40 metric tons

# Bhopal Industrial Disaster

**Date:** December 2-3, 1984

**Location:** Bhopal, India

**Site:** Bhopal Pesticide & Herbicide Chemical Plant (Union Carbide India Limited)

**Event:** Introduction (accidental or intentional ???) of significant amounts of water into a tank storing 40 metric tons of methyl isocyanate produced a highly exothermic reaction. Significant amount of CO<sub>2</sub> was generated increasing tank pressure. 40 tons of methyl isocyanate were released into the atmosphere -- references (a), (b) and (c).

Release would have been harmless if it had passed through the NaOH scrubbers in the exhaust lines; however, on this day, the scrubbers were not working. (Ref (a))

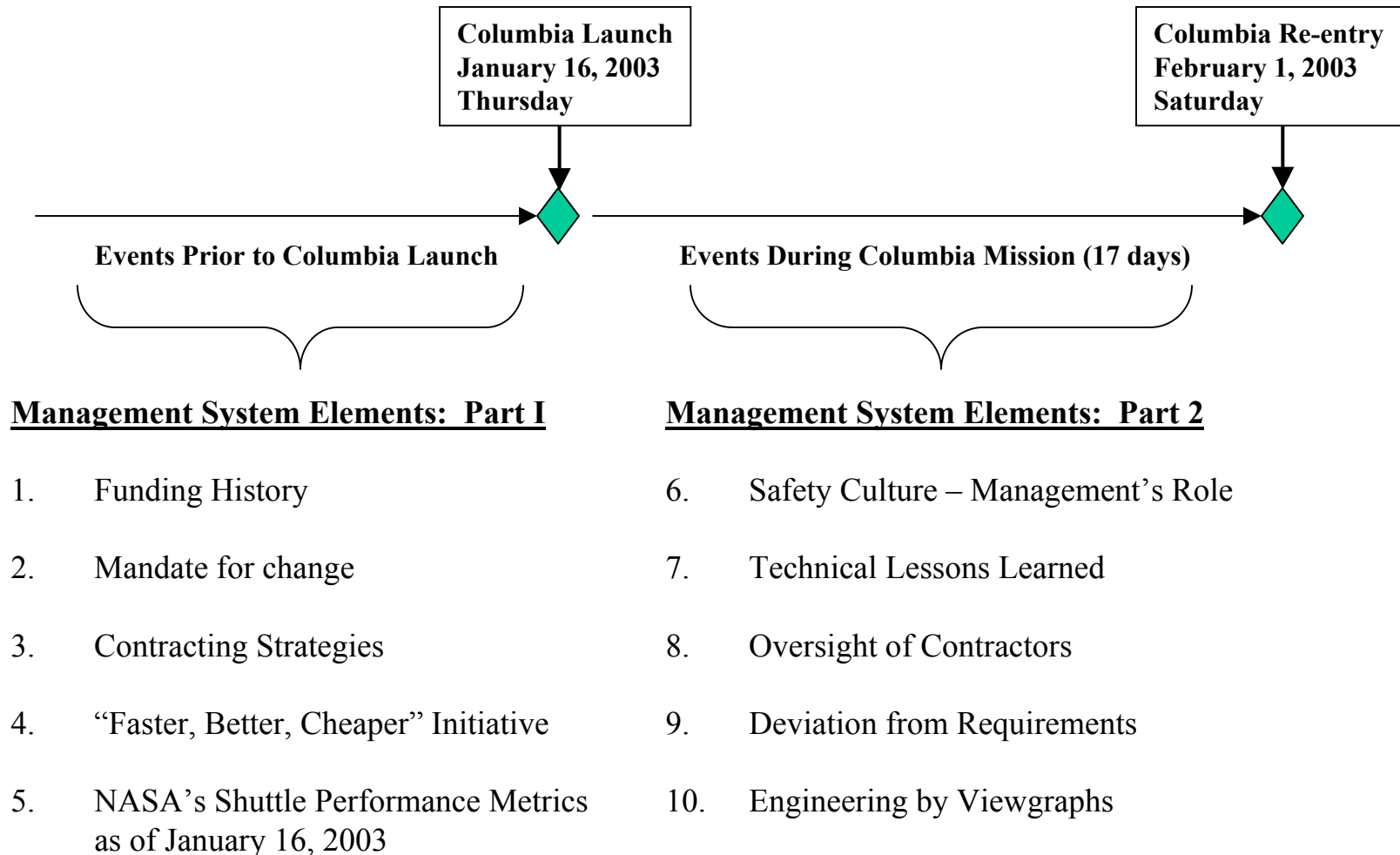
**Casualties:** 3,800 people died  
2,720 people were permanently disabled (total or partial)  
170,000 people incurred significant adverse health effects

**References:** (a) [www.chm.bris.ac.uk/webprojects2002/tan/bhopal\\_disaster.htm](http://www.chm.bris.ac.uk/webprojects2002/tan/bhopal_disaster.htm)  
(b) [www.bhopal.com/facts.htm](http://www.bhopal.com/facts.htm)  
(c) [www.epa.gov/ttn/atw/hlthef/methylis.html](http://www.epa.gov/ttn/atw/hlthef/methylis.html)



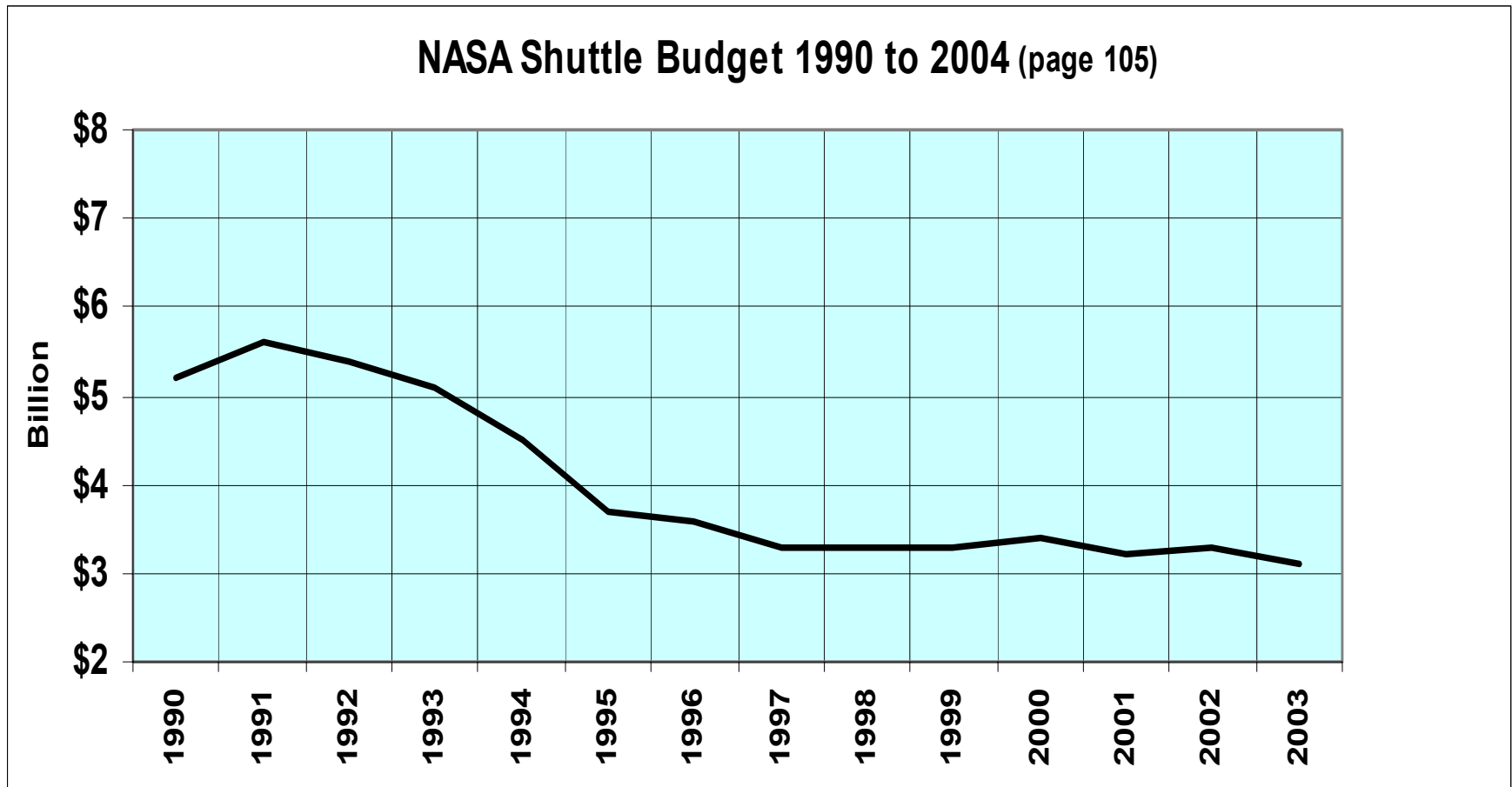
# Timeline of NASA's Major Managerial Changes, Events and Decisions

This briefing focuses on the following specific elements and “vertical cuts” into the NASA management system.

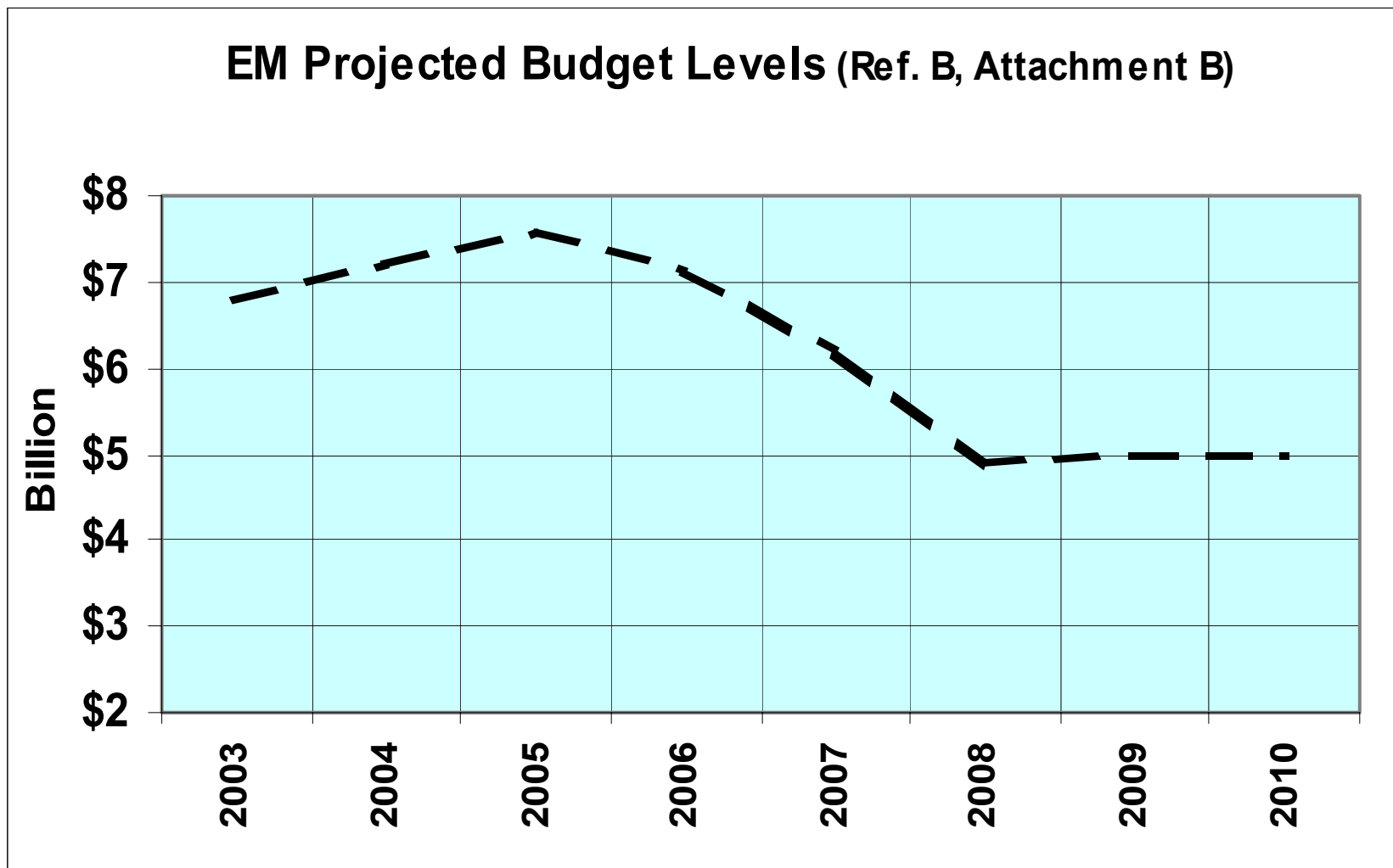




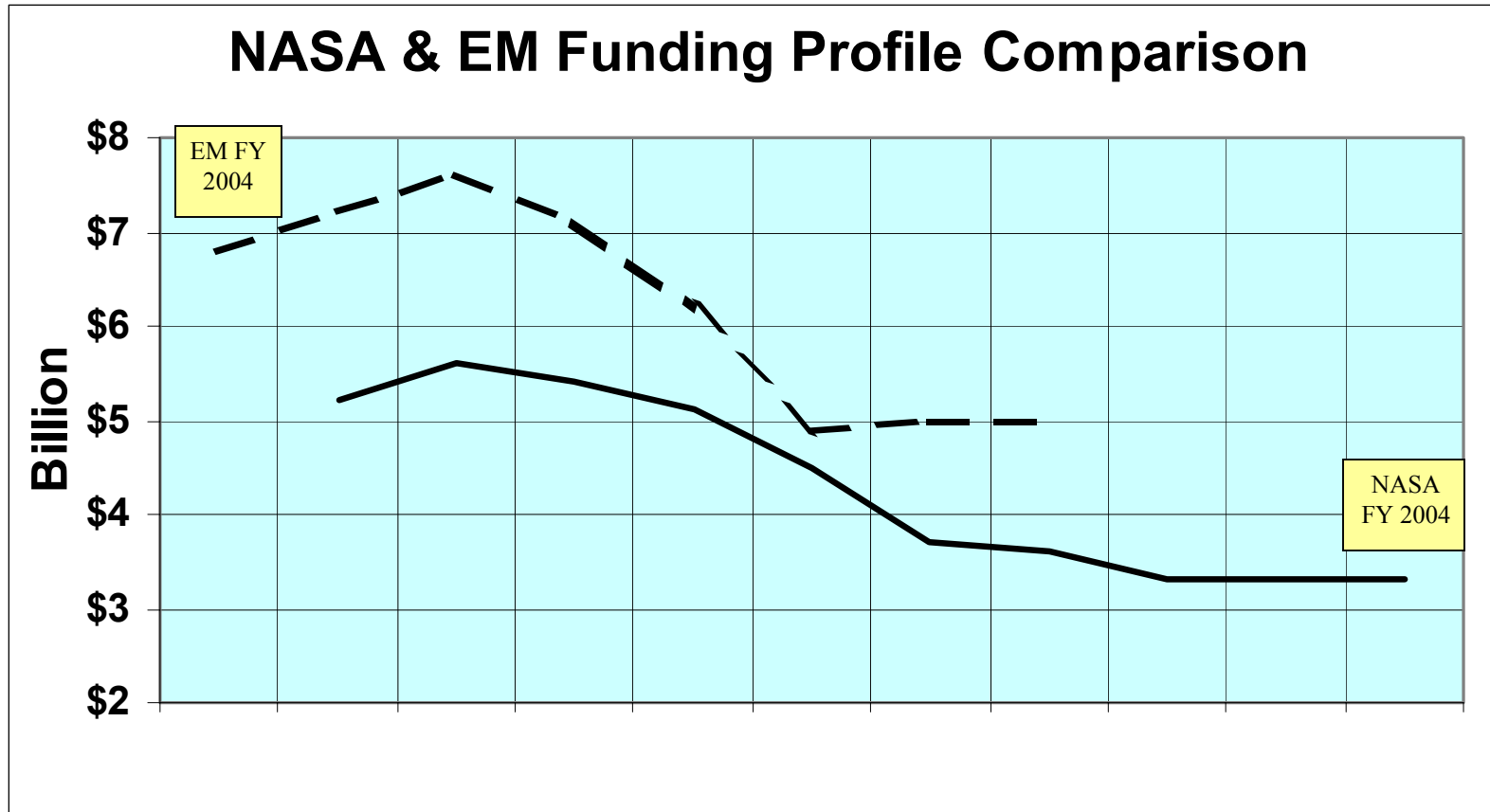
## 1. NASA Funding History:



## 1. NASA Funding History (continued):



## 1. NASA Funding History (continued):



## 2 & 3: Change & Contracting Strategies (1990 - 2003) (page 105)

**1992** - Dan Goldin becomes the NASA Administrator. Institutes “not evolutionary change, but radical or discontinuous change.” (page 105)

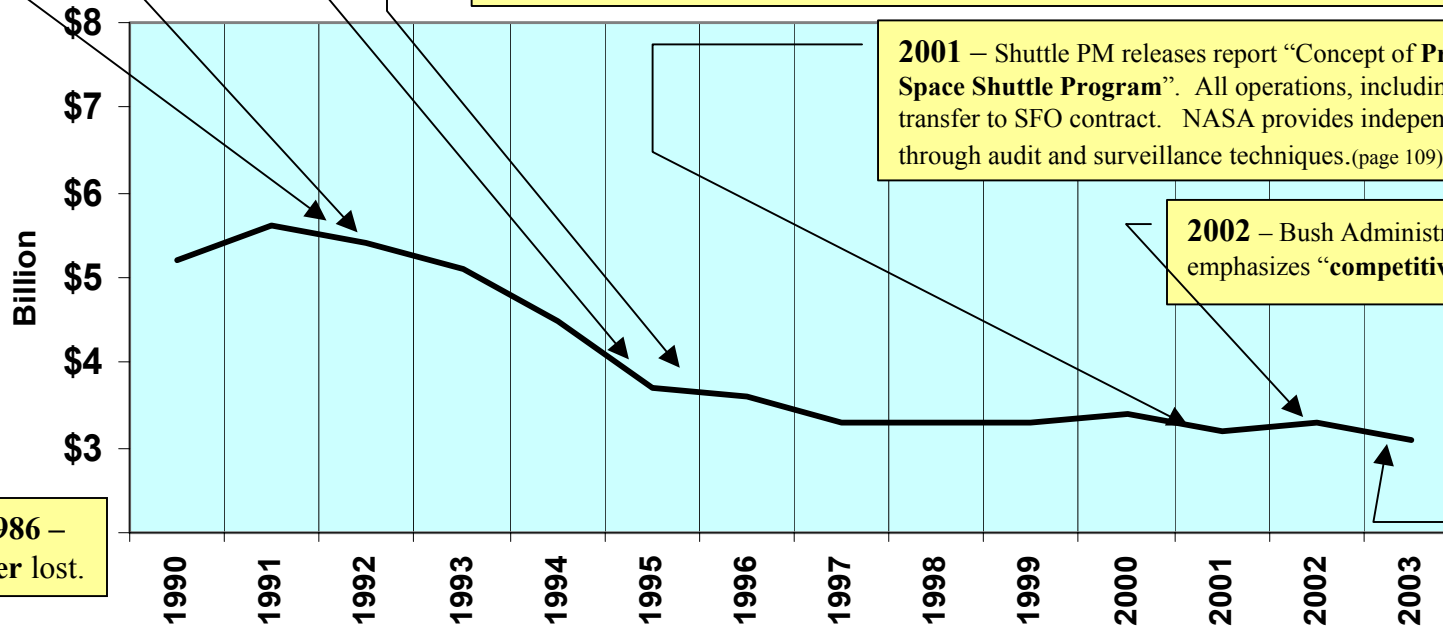
**1992** – Dan Goldin initiates the “**Faster, Better. Cheaper**” approach to planning of robotic missions within the solar system and NASA downsizing. This effort spans 1992 to 1999. (page 106)

**1995** – (March) Kraft Report: “...a new mode of management with considerably **less NASA oversight** is possible at this time.” (page 108)

**1995** – (November) NASA awards 6 year Space Flight Operations contract to United Space Alliance (Lockheed Martin & Rockwell) on a sole source basis. Contract was a **performance based contract** – to earn fee company had to meet a series of **safety “gates”** to ensure safety remained a top priority. Company also was rewarded for cost reductions (**65% - 35% split**). Saved \$1 billion from 1996 to 2002. (page 108)

**2001** – Shuttle PM releases report “**Concept of Privatization of the Space Shuttle Program**”. All operations, including Astronauts, transfer to SFO contract. NASA provides independent assessment through audit and surveillance techniques.(page 109)

**2002** – Bush Administration takes over; emphasizes “**competitive outsourcing**” (110)



**Jan 28, 1986** – Challenger lost.

**Feb. 1, 2003:** Columbia Lost

## 4. “Faster, Better, Cheaper” Initiative

- The **Challenger** disaster caused NASA to review its approach toward project management
- Prior to 1990, NASA managed large, expensive, long duration programs and projects (Apollo, Shuttle, Viking, Hubble Telescope)
- NASA had the choice of either eliminating major programs or achieving greater efficiency while maintaining its existing agenda. (103)
- NASA chose to emphasize doing more with less.
- Increased the number of smaller projects and focused on doing them in a way that emphasized safety, innovation, low cost, speed and quality.
- Titled: “Faster, Better, Cheaper”

### Solar System Exploration Projects Undertaken with “Faster, Better, Cheaper”

Year	Title	Mission
1996 (Launched)	Mars Global Surveyor	Extraordinary <b>successful</b> . First Mars mission using “Faster, Better, Cheaper” initiative.
1997 (Landed)	Mars Pathfinder	Landed on Mars with Lander and Rover operations. Highly visible <b>success</b> .
1998 (Launched)	Deep Space I	<b>New technologies</b> including ion propulsion and onboard autonomous computer control operations.
1998 (Launched)	Mars Climate Orbiter	<b>Failure</b> . Navigation error sent to spacecraft into Mars atmosphere instead of its planned orbit. (English unit system vs. metric unit system)
1999 (Launched)	Mars Polar Lander	<b>Failure</b> . When lander legs were deployed during descent, the system interpreted the signal to mean the lander had landed, resulting in a premature shutdown of the lander engines—the lander crashed into the Mars surface.
1999 (Launched)	Deep Space II	<b>Failure</b> .

## 4. “Faster, Better, Cheaper” Initiative (con’t)

NASA’s self initiated, independent investigations revealed several major causes of failure:

<u>Cause</u>	<u>Discussion</u>
<b>Inexperienced Project Managers</b>	<ul style="list-style-type: none"><li>• As number of smaller projects increased, there were not enough “experienced” project managers</li><li>• Senior management involvement was not increased to compensate for lack of experience. (Ref (d) – page 5)</li></ul>
<b>Project Manager had split responsibility</b>	<ul style="list-style-type: none"><li>• The failed projects had split responsibility. One Project Manager was responsible for development, another Project Manager was responsible for operations and launch. (Ref (d) – page 5)</li></ul>
<b>Program constraints increased risk</b>	<ul style="list-style-type: none"><li>• Many project elements were fixed:<ul style="list-style-type: none"><li>Schedule: Fixed launch window</li><li>Scope: science experiments, mission objectives</li><li>Weight: Launch vehicle had fixed payload limits</li><li>Cost: Projects were “Fixed Cost”</li></ul></li><li>• With all elements “fixed”, the only project element that could change was “risk”</li><li>• Risk management was not a well defined, formalized effort. (Ref (d) – page 6)</li></ul>
<b>Institutional experience was eliminated without compensatory actions.</b>	<ul style="list-style-type: none"><li>• For more that 40 years, significant investments were made at the Jet Propulsion Laboratory. When these assets were eliminated due to cost considerations, no compensating activities or resources were made available. (Ref (d) – page 7)</li></ul>
<b>Contractor was not required to notify NASA of increasing risk.</b>	<ul style="list-style-type: none"><li>• Day-to-day relationships with the contractor were positive. However, the relationship was ineffective when it came to informing senior management about risk.</li><li>• The contractor did not formally identify risk or deviations from acceptable practice. (Ref (d) – page 10)</li></ul>
<b>“Faster, Better, Cheaper” encouraged risk taking.</b>	<ul style="list-style-type: none"><li>• FBC encourages taking risk in utilizing new technology and pursuing important science objectives and innovation. However, risk must be identified, tracked and mitigated. (Ref (d) – page 7)</li></ul>

## 5. NASA's Shuttle Performance Metrics as of January 2003:

### I. Since January 1986 (Challenger Loss):

**86** Space Shuttle missions scheduled, and

**86** Space Shuttle missions completed successfully!

### II. Challenging future goals:

By February 2004: Complete the US portion of international space station: **“US Core Complete”**

*“Space Station was over-budget & behind schedule. To regain credibility with Congress and the White House, completing the US portion of the Space Station on time would prove NASA could meet schedules and budgets” (131)*

To achieve US portion of the international space station by February 2004, shuttle program scheduled **10 space shuttle missions in 16 months.**

The international space station was a major **corporate commitment communicated to all NASA employees.** One example: NASA developed and used a computer “screen saver” that provided a continuous countdown to the “US Core Complete” milestone for the International Space Station.



# Columbia Accident Investigation Report

And

## The Office of Environmental Management

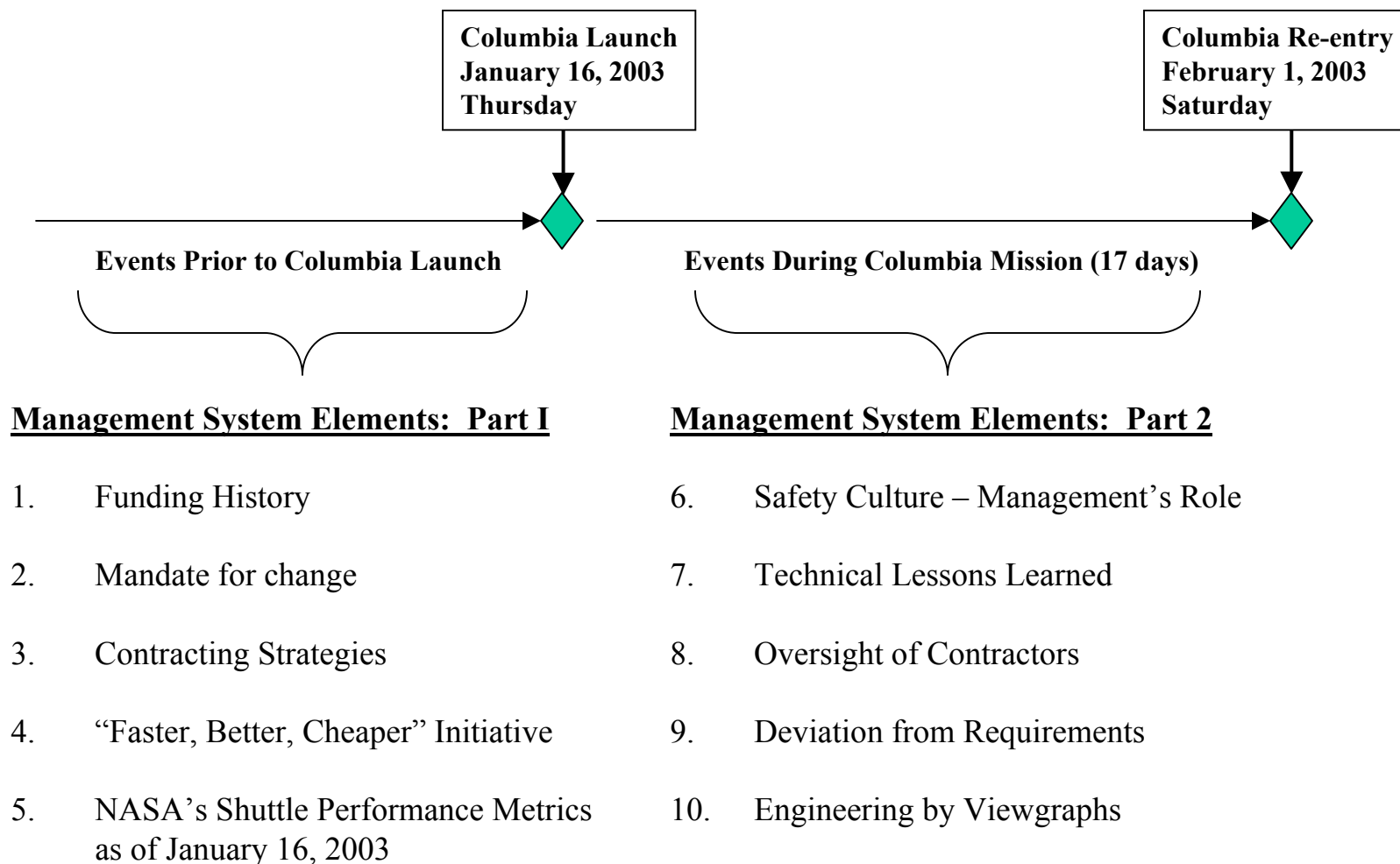
“Part 2”

*“Organizational culture defines the assumptions that employees make as they carry out their work; it defines “the way we do things here.” It is a powerful force that persists through reorganizations and the departure of key personnel.” (page 101)*

Columbia Accident Investigation Board Report  
Volume I, August 2003

# Timeline of NASA's Major Managerial Changes, Events and Decisions

This briefing focuses on the following specific elements and “drills down” into the NASA management system.



## 6. Safety Culture – Management’s Role

### Issue

### Investigation Board Comments

**Effective Safety Program - at the floor level**

•“The Board believes the space shuttle program has effective safety practices at the “shop floor level” (186)

**Management did not fully understand its safety culture**

•“NASA management espoused a risk-averse philosophy that empowered any employee to stop an operation at the mere glimmer of a problem. NASA’s views of its safety culture did not reflect reality” (177)

•“NASA workers had a legendary can-do attitude. When workers were asked to find schedule margin, they worked feverishly to do so, and were praised when they succeeded. These same people have difficulty admitting something shouldn’t be done. In reality, no one at NASA wanted to be the one to stand up and say, “We can’t make that date.” (138)

•“Organizational culture defines the assumptions that employees make as they carry out their work; it defines” the way we do things here.” It is a powerful force that persists through reorganizations and the departure of key personnel.” (101)

**Safety Blind Spots**

•“There were blind spots in the NASA safety culture” (184) , “Its safety culture no longer asked hard questions.” (185)

•“**Institutional practices that were in effect at the time of the Challenger accident, such as inadequate concern for deviations, a silent safety program, and schedule pressure – had returned to NASA.**” (101)

**Competing responsibilities**

•Chairperson of the Mission Management Team was also the Launch Integration Manager for the next shuttle launch. “Her inquiries about the foam strike were not to determine action to take during the Columbia mission, but to understand the implication for the next shuttle launch.” (139)

**Some manager’s questions were “closed questions” not “open questions”**

“No burn through, means no catastrophic damage?” (161)

“No safety of flight, no issue for this mission, nothing that we’re going to do differently?” (161)

**Not enough thinking time**

“Workers were uncomfortable with the rapid sequence of shuttle flights. “.....I wasn’t convinced that people were being given enough time to work the problems correctly.” (134)

**Buying Safety Services**

“Buying safety services ..... Preclude the safety organization from effectively providing independent safety analysis.” (186)

## 7. Silent Safety Program: Some Characteristics

<u>Issue</u>	<u>Investigation Board Comments</u>
<b>Silence</b>	<ul style="list-style-type: none"><li>•“The silence of Program-level safety processes undermined oversight; when they did not speak up, safety personnel could not fulfill their stated mission to provide “checks and balances.” (page 178)</li><li>•Safety personnel were present but passive .....” (page 170)</li></ul>
<b>“...simply listened and concurred.”</b>	<ul style="list-style-type: none"><li>•“No safety representatives were present during the Challenger teleconference – no one even thought to call them. In the case of Columbia, safety representatives were present at ... Team meetings; however, rather than critically question or actively participate in the analysis, the safety representatives simply listened and concurred.: (page 202)</li></ul>
<b>Leadership’s role</b>	<ul style="list-style-type: none"><li>•“Organizations with strong safety cultures generally acknowledge that a leader’s best response to unanimous consent is to play devil’s advocate and encourage an exhaustive debate. .... Imagine the difference if any Shuttle manager had simply asked, “Prove to me that Columbia has not been harmed.” (page 192)</li><li>•...some Space Shuttle Program managers failed to fulfill the implicit contract to do whatever is possible to ensure the safety of the crew.” (page 170)</li></ul>
<b>Example of successful independent safety programs do exist.</b>	<ul style="list-style-type: none"><li>•Elements of successful programs include:<ul style="list-style-type: none"><li>– Communication and action</li><li>– Recurring training and learning from mistakes</li><li>– Encouraging minority opinions</li><li>– Retaining knowledge</li><li>– Worst-case event failure analysis (page 183)</li></ul></li></ul>
<b>Skepticism</b>	<ul style="list-style-type: none"><li>•“The intellectual curiosity and skepticism that a solid safety culture requires was almost entirely absent.” (page 181)</li><li>•“NASA’s safety culture has become reactive, complacent, and dominated by unjustified optimism.” (page 180)</li></ul>

## 8. Technical Lessons Learned

Figure 6.1-7 Significant Thermal Protection System Damage or major foam loss. (page 128)

Date	Launch	Tile Damage
Apr 1981	1	Lots of debris damage. 300 tiles replaced.
Jun 1983	7	<b>First</b> known left bipod ramp form shedding event.
<b>Dec 1988</b>	<b>27</b>	<b>Debris knocks off tile. Near burn through results.</b>
Jan 1990	33	<b>Second</b> known left bipod ramp foam event.
Dec 1990	38	NASA classifies foam loss a “safety of flight issue”
Jan 1992	45	First flight after after next mission launched without debris In-Flight Anomaly closure/resolution.
Mar1992	46	Damage to wing leading edge. Unexplained Anomaly.
Jun 1992	48	<b>Third</b> known bipod ramp foam loss.
Oct 1992	51	<b>Fourth</b> known bipod ramp foam loss.
Apr 1993	54	Large area tile damage.
Oct 1994	61	<b>Fifth</b> known bipod ramp foam loss.
Nov 1997	88	Damage to tiles spurs NASA to initiate tests to resolve foam loss. In-Flight Anomaly of foam loss classified as “acceptable risk.”
Oct 2002	111	<b>Sixth</b> known left bipod ramp foam loss. Major damage to the external fuel tank.
Jan 2003	113	<b>Seventh</b> known left bipod ramp foam loss.

## 8. Technical Lessons Learned (continued)

<u>Issue</u>	<u>Investigation Board Comments</u>
<b>Foam loss is a dangerous problem.</b>	<ul style="list-style-type: none"><li>•“Early in the space shuttle program, foam loss was considered a dangerous problem” (121)</li></ul>
<b>December 1988 (Launch #27)</b>	<ul style="list-style-type: none"><li>•“Damage occurred 85 seconds into flight.(Columbia damage occurred at 81.9 seconds) Location of tile damage had thick aluminum plate covering an antenna, otherwise “<b>burn-through</b>” may have occurred.” (127)</li><li>• Crew was asked to inspect for potential damage with remote arm and camera. (127)</li></ul>
<b>January 2003 – Columbia (Launch #113)</b>	<ul style="list-style-type: none"><li>•Foam strike discovered on day 2, Shuttle Program Manager:<ul style="list-style-type: none"><li>–Declined to have crew check for damage</li><li>–Declined to request on-orbit imagery from Air Force and National imaging assets</li><li>–Discounted the possibly of burn-through (127)</li></ul></li></ul>
<b>Institutional Memory Failure</b>	<ul style="list-style-type: none"><li>•“The Board views this failure as an illustration of the lack of institutional memory in the Space Shuttle Program – NASA is not functioning as a learning organization.” (127)</li></ul>

**Handout:** DOE Type A and Type B Investigation Summary

## 9. Deviations from Standards

**“3.2.1.2.1.4 Debris Prevention:** The Space Shuttle System, including the ground systems, shall be designed to preclude the shedding of ice and/or other debris from the Shuttle elements that would jeopardize the flight crew, vehicle, mission success, or would adversely impact turnaround operations.” (122)

**“3.2.1.1.17 External Tank Debris Limits:** No debris shall emanate from the critical zone of the External Tank on the launch pad or during ascent except for such material which may result from normal thermal protection system recession due to ascent heating.” (122)

<u>Issue</u>	<u>Investigation Board Comments</u>
<b>Design Requirements were frequently violated.</b>	“NASA management came to see the problem with o-rings (Challenger) and foam strikes (Columbia) as an acceptable flight risk. Both were violations of design requirements, but management believed the violations could be tolerated.” (100)
<b>Safety system was silent</b>	“The checks and balances the safety system was meant to provide were not working (I.e., operating within design requirements (an initial condition for safety analysis) was not occurring.” (100)
<b>Challenger culture returned</b>	“Institutional practices that were in effect at the time of Challenger accident – such as inadequate concerns over deviations from expected performance, a silent safety program, and scheduling pressures had returned to NASA.” (101)
<b>Senior management accepted frequent violations of design requirements</b>	“Foam losses that violated design requirements came to be defined by NASA management as an acceptable aspect of Shuttle missions – one that posed merely a maintenance “turnaround” problem rather than a safety of flight issue.” (121)



## 10. Oversight of Contractors

Upon discovery of the foam strike, contractor engineers commenced computer simulation analysis to assess potential damage. An existing tile damage prediction tool, CRATER, was used to predict how small debris, usually ice, could damage the Orbiter during launch. (143)

<u>Issue</u>	<u>Investigation Board Comments</u>
<b>Technical Unfamiliarity</b>	•“Unfamiliar with CRATER, NASA engineers and managers had to rely on the contractors for analysis and interpretation, and did not have the training necessary to evaluate the results.” (202)
<b>Contractor and software limitations existed</b>	•“Contractor engineers had received training on CRATER model, but only used it twice before.” (145) •“Contractor engineers had reservations about using the CRATER model to model the foam debris that struck Columbia; however, they did not consult with Boeing’s engineers who usually perform the analysis.” (145)
<b>Contractor just reorganized</b>	•“Boeing’s Huntington Beach , California facility, who up until the Columbia launch had performed or overseen CRATER analysis, had transferred responsibilities for CRATER analysis in January 2003 to its Houston office.”(145) •“CRATER predicted damage to the tile deeper than the tile’s actual thickness, predicting damage to the airframe.” (145) •“Results were discounted by engineers because actual results were usually less than computer predictions.”(145) •“Engineers assumed the debris did not penetrate the Orbiter’s skin.” (145)
<b>Computer model validation envelope.</b>	•Many of the Columbia’s debris characteristics were orders of magnitude outside of its validated envelope. For example: CRATER was designed and validated for projectiles up to 3 in <sup>3</sup> . The Columbia’s debris was estimated at 1,200 in <sup>3</sup> (400 x larger). (144)
<b>More intensive oversight needed</b>	•“The increased reliance on contractors necessitated more effective communications and more extensive safety oversight processes than had been in place during the APOLLO era.” (102)

**Handout:** “Video Game” or “Credible Simulation Model”

## 11. Engineering by Viewgraphs

The Debris Assessment Team presented its formal analysis of the foam strike potential damage to the Mission Evaluation Team. The following Board comments relate to the quality and substance of the briefing slide. The slide is provided on page 191 of the report.

<u>Issue</u>	<u>Investigation Board Comments</u>
<b>Analysis Results</b>	<ul style="list-style-type: none"><li>•Power Point slide structure downplayed the significance of the event, test results and analysis limitations. (191)</li><li>•Used vague words “significant” and “significantly”. It contained no quantitative statistical data or information. (191)</li><li>•The key piece of information, one that estimates the debris that struck the Columbia was 640 times larger than the data used to calibrate the computer model, was placed at the bottom of the slide, with a third priority heading. (191)</li></ul>
<b>Message Dilution</b>	<ul style="list-style-type: none"><li>•“As information gets passed up an organization hierarchy, from people who do analysis to mid-level managers to high-level leadership, key explanations and supporting information is filtered out.” (191)</li></ul>
<b>Foam Damage Briefing</b>	<ul style="list-style-type: none"><li>•“It is easy to understand how a senior NASA manager might read this Power Point slide and not realize that it addressed a life-threatening situation.” (191)</li></ul>
<b>Technical Communication</b>	<ul style="list-style-type: none"><li>•“At many points during its investigation, the Board was surprised to receive similar presentation slides from NASA officials in place of technical reports.” (191)</li><li>•The Board views the endemic use of Power Point slides instead of technical papers as an illustration of the problematic methods of technical communication at NASA.” (191)</li></ul>

## Summary

Based on NASA lessons learned, as identified in the *Columbia Accident Investigation Board Report*, oversight of a safety management system should assess:

Element	Slide Number
1. Inexperienced Project Managers without experienced mentoring.	14
2. Project managers have split responsibility and/or competing responsibilities	14
3. Programmatic constraints (scope, schedule, and cost) without a focus on risk management	14
4. Eliminating institutional experience without compensatory actions.	14
5. Contractor is not required to notify the client of increasing risk.	14
6. Management initiatives (“Faster, Better, Cheaper”) encourage risk taking without a focus on risk management	14
7. Effective safety program at the floor level, but management does not understand its role in its safety culture	18
8. Safety blind spots	18
9. Managers tendency to ask “closed questions” not “open questions”	18
10. Buying safety services	18
11. Silent Safety Program: “...simply listened and concurred.” Leadership’s role Healthy skepticism	19

### Summary (continued)

Based on NASA lessons learned, as identified in the *Columbia Accident Investigation Board Report*, oversight of a safety management system should assess:

Element	Slide Number
12. Institutional Memory Failure – Lack of an effective Lessons Learned program.	21
13. Violating design requirements.	22
14. Oversight of Contractors: Technical unfamiliarity Contractors just reorganized	23
15. Knowing the difference between “Credible Computer Simulation Model” and a “Video Game”	23
16. Technical Communication: Engineering by Power Point viewgraphs Are Power Point slides used for convenience or necessity? Message dilution (KISS, dumbing-down the technical message)	24

## Other References:

### Topic

NASA's "Faster, Better, Cheaper" Initiative

### References

- d) Mars Program Independent Assessment Team Report (March 14, 2002) available on [http://spaceflight.nasa.gov/spacenews/releases/2000/mpl/mpiат\\_summary.pdf](http://spaceflight.nasa.gov/spacenews/releases/2000/mpl/mpiат_summary.pdf)
- e) NASA, Office of Inspector General Report (IG-01-09): Faster, Better, Cheaper: Policy, Strategic Planning, and Human Resource Alignment (March 13, 2001)
- f) EM-1 Memo "FY 05 Budget Formulation & Lifecycle Planning Guidance" (March 14, 2003, Attachment B "EM FY 2005 – FY2009 Target Estimates").

EM Projected Budget Profile